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Experimental transplants reveal strong environmental effects on the growth of non-vascular epiphytes in Afromontane forests

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ABSTRACT

Transplant studies can provide valuable information on the growth responses of epiphytic bryophytes and lichens to environmental factors. We studied the growth of six epiphyte species at three sites in moist Afromontane forests of Taita Hills, Kenya. With 558 pendant transplants, we documented the growth of four bryophytes and two lichens over 1 yr. The transplants were placed into the lower canopy of one forest site in an upper montane zone, and two forest sites in a lower montane zone. Several pendant moss species grew very well in the cool and humid environment of the upper montane forest, with some transplants more than doubling their biomass during the year. Conversely, all transplanted taxa performed poorly in the lower montane zone, presumably because of the unfavorable combination of ample moisture with excessive warmth and insufficient light which characterizes the lower canopy in dense lower montane forests. The results demonstrate that pendant transplants can be used for monitoring growth of non-vascular epiphytes in tropical forests. The starting weight of 0.25 g for pendant transplants worked well and can be recommended for future studies.

Key words: canopy; *Heterodermia*; microclimate; moss; *Orthostichella*; *Squamidium*; *Usnea*; vegetation.

EPIPHYTIC LICHENS AND BRYOPHYTES ARE IMPORTANT COMPONENTS OF BIODIVERSITY IN MONTANE TROPICAL FORESTS. As they primarily rely on the atmosphere for water and inorganic nutrients, absorbing these through their entire surface, water uptake from mist and dew is essential to their ecology (Gauslaa 2014). Upper montane forests tend to receive ample rain and often experience a high frequency of mist, and thus provide optimal conditions for epiphyte growth. Hence, abundant epiphyte cover is one physiognomic feature that helps to distinguish upper montane 'moss forests' from drier lower montane forests (Frahm & Gradstein 1991, Martin et al. 2010, Frisch et al. 2015). The abundance of epiphytic bryophytes and lichens in tropical upper montane forests is explained by the beneficial combination of ample moisture and light with relatively cool temperatures (Zotz 1999, Zotz & Schleicher et al. 2003, León-Vargas et al. 2006). Because they capture moisture from mist and dew, much of which eventually drips to the forest floor, and help maintain high atmospheric humidity through evapotranspiration, the epiphytes themselves influence the hydrology of montane forests (Stanton & Horn 2013, Stanton et al. 2014).

Numerous tropical epiphyte species are currently threatened by habitat destruction, forest clearing, and/or air pollution (Alvarenga et al. 2009, Benítez et al. 2012). Some epiphytes are extremely sensitive to disturbance, and climate change represents a serious threat to entire epiphyte communities (Zotz & Bader 2009, Zartman et al. 2015, He et al. 2016). The effects on epiphytic bryophytes of upper montane forests may be particularly severe as many of the resident species are desiccation intolerant (Nadkarni 2010, Pardow & Lakatos 2013).

Transplant studies offer a practical way of quantifying the growth and determining habitat responses of epiphytic bryophytes and lichens. In boreal and temperate regions, transplant studies have been widely used to investigate the growth responses of different epiphytes to various habitat conditions (e.g., Larson et al. 2012, Song et al. 2012), effects of air pollution (e.g., Bignal et al. 2008), and within the framework of in situ conservation (e.g., Gunnarsson & Söderström 2007). However, few studies have used tropical epiphyte species (e.g., Clark et al. 1998, Nadkarni & Solano 2002).

Basic data on the biomass distribution and growth potential of tropical epiphytic bryophytes and lichens are required to quantify their specific roles in the hydrology of upper montane forests, which often function as important water catchment areas for surrounding lowlands (Bruijnzeel et al. 2010). When such data become available, epiphyte transplants could also be used to quantify the amount of water intercepted and released by different epiphytes, to evaluate their overall role in the regional water balance, and finally to model their water capture potential over tropical mountain landscapes. Such models could be used to prioritize reforestation efforts when restoring the primary ecosystem service of deforested tropical mountains as regional 'water towers' (e.g., Akotsi et al. 2006).

Due to the lack of published information on the growth of epiphytic bryophytes and lichens in tropical ecosystems, and in African forests in particular, we conducted transplantation experiments in the montane forests of Taita Hills, Kenya, where cryptogamic epiphytes, especially pendant bryophytes, are more abundant in moist upper montane forests than in drier lower montane forests (Aerts et al. 2010, Enroth et al. 2013). We sought to determine if the conspicuous difference in epiphyte biomass reflects inherent differences in the ability of dominant epiphytes to grow within the two contrasting habitats, and if the growth responses of various epiphyte species differed. We placed hundreds of pendant transplants into one forest site in the upper montane zone and two sites in the lower montane zone, and compared transplant growth over 1 yr. We also examined if transplant size or transplantation height influenced their growth responses.

We transplanted three pendant mosses (*Orthostichella rigida*, *Orthostichella capillicaulis*, and *Squamidium brasiliense*), one leafy liverwort (*Plagiochila* sp.), and two fruticose lichens (*Heterodermia leucomelos* and *Usnea* sp.) from the upper montane zone. We tested the following hypotheses: (1) Epiphyte transplants can be used to document growth of epiphytic bryophytes and lichens in tropical forests; (2) Growth responses of epiphyte species differ when they are transplanted into upper and lower montane forests; (3) Small transplants grow less because they are more prone to weight loss through thallus fragmentation; (4) Transplantation height influences transplant growth, the lower canopy receives less light; and (5) Growth responses of individual transplants during sequential seasons tend to differ due to climatic variation and gradual acclimatization of transplants to new conditions.

METHODS

STUDY AREA.—The Taita Hills, surrounded by the Tsavo Plains, are in southeastern Kenya (Fig. S1—Online Supplementary Material). The Tsavo Plains lie 500–600 m asl, while the highest peak of Taita Hills (Vuria) is at 2208 m. The mountains form the northernmost part of the Eastern Arc

Mountains, crystalline block-faulted mountains formed 290–180 Myr BP (Burgess et al. 2007), and represent a well-known biodiversity hot spot (Myers et al. 2000, Dimitrov et al. 2012).

The Taita Hills experience long rains between March and May, and a shorter rainy season between November and December. The average annual rainfall on the plains is about 500 mm, while the mountains receive over 1000 mm of rain (Pellikka et al. 2009). Due to long-lasting and intensive human influence the indigenous moist montane forests on the upper slopes have been reduced to tiny remnant patches (Pellikka et al. 2009, Aerts et al. 2010, Malombe et al. 2016).

We monitored the performance of bryophyte and lichen transplants in three study sites in the Taita Hills (Fig. S1—Online Supplementary Material). One study site was near the summit of Vuria Mountain (3°240 S, 38°170 E, 2189 m asl). The upper slopes of Vuria receive abundant moisture from low-lying clouds and fog and are hence wetter than most other forests in the Taita Hills (Table 1). The forest at the study site is best described as degraded elfin forest or upper montane cloud forest. The two other study sites were both in the Ngangao Forest, a drier (Fig. S1—Online Supplementary Material; Table 1) lower montane cloud forest on the steep eastern slope of a north-south– oriented mountain ridge. The first plot was in Ngangao South (3°220 N, 8°200 E, 1856 m asl), and the second plot in Ngangao North (3°210 S, 38°200 E, 1877 m asl).

No long-term climatic data are presently available from the Taita Hills. Irregular weather data are available from 2011 onward from eight small weather observation stations. In addition, weather variability has been studied at 40 sites with iButton Hygrochron temperature and humidity loggers (DS1923a 2013) placed to a height of 1.5 m (Virtanen 2015). We used this and other unpublished data to tentatively characterize differences in the forest microclimates of the three study sites in Table 1.

PENDANT TRANSPLANTS.—For the transplant experiments we used easily identifiable pendent or fruticose species that were common in the epiphyte communities of tree stems and branches in the study area. All the selected epiphytes are relatively large and have a pendent or semi-pendent way of growth. We collected abundant fresh material of three epiphytic mosses (*Orthostichella rigida*, *Orthostichella capillicaulis*, and *Squamidium brasiliense*), one leafy liverwort (*Plagiochila* sp.), and two fruticose lichens (*Heterodermia leucomelos* and *Usnea* sp.) from the Vuria forest close to the summit of the mountain (elev. 2200 m) in early December 2012.

In the laboratory, we chose several young shoots of the bryophyte or thallus lobes or branches of the lichen species. We adjusted the amount of biological material so that the air-dry weight in each transplant was about 0.25 grams (0.24–0.26 g). We chose this size based on previous studies and pilot experiments. McCune et al. (1996) used transplants weighing 0.1–0.3 g. They had earlier concluded that transplants weighing 0.14 g were too small and recommended doubling the size of the samples (Peck et al. 2000). After weighing, we wrapped each transplant in a piece of green plastic (PE) net with an aperture of 8 x 8 mm, and sealed both ends of the roll with cable ties. We tied each bag to a 3–5 cm loop of fishing line with a double overhand knot, which we then inserted in silicone and left to dry indoors (unheated room) for 24 h. We then trimmed the ends of the knots and weighed the rigged pendants again. The weight of the rigging was typically 0.4–1.1 g, depending on slight differences in the amount of plastic net, cable tie, and silicone used. We coded each rigged pendant for identification using colored plastic beads, and attached them to ropes according to the design of the growth experiments (Fig. S2—Online Supplementary Material).

As recommended by McCune et al. (1996), we also weighed several calibration specimens (ca. 0.25 g) of each epiphyte species together with the transplants and stored them dry in the laboratory. Later we weighed them together with the field transplants, to detect possible weight changes in the transplants due to differences in ambient air humidity. In addition, we constructed empty control nets and placed them in the field together with transplants to detect possible changes in the weight of the plastic ridding during the course of the experiment.

EXPERIMENTAL SETUP.—We constructed and placed in the field all 558 epiphyte transplants within 4 weeks between December 2012 and January 2013. In order to incorporate all the different epiphyte species and have a sufficient number of replicate transplants of each species at each site, and to answer several different research questions, we divided the transplants into three groups (test ropes A–C) as follows. We collected the primary data set on epiphyte growth with 324 epiphyte transplants attached to 36 test ropes (A test ropes). Half of these (A1 test ropes) had one control net and nine epiphyte transplants, consisting of three replicates each of *Orthostichella rigida*, *Heterodermia leucomelos*, and *Usnea* sp. The second half (A2 test ropes) also had nine epiphyte transplants, consisting of three replicates each of *Orthostichella capillicaulis*, *Squamidium brasiliense*, and *Plagiochila* sp. The order of the transplants on each rope was identical and we never placed two replicates of the same epiphyte species side by side. We randomly organized the A test ropes into 18 pairs of A1 and A2 test ropes, and placed 6 pairs into each of the three forest study sites in the Taita Hills. At the field sites, we attached each test rope between two tree trunks or between the branches of a single tree and left it suspended at the height of three meters. We carefully selected the attachment points of each rope so that each transplant was suspended in open air and not too close to neighboring branches and etc. We did this to standardize the growth conditions as much as possible and to help control transplant losses through abrasion by neighboring branches, by monkeys, etc.

As we did not know what the effects of transplant size on epiphyte growth would be, we tested if there were differences between the primary transplants (all weighing ca. 0.25 g) and two sets of larger transplants. We attached three transplants each of *Orthostichella rigida* and *Heterodermia leucomelos*, weighing 0.5 g (B1 test ropes) or 1 g (B2 test ropes) to each rope. We randomly organized 12 such ropes (with a total of 72 epiphyte transplants) into 6 pairs of B1 and B2 test ropes. We brought two pairs of test ropes to each of the three forest study sites and suspended them between tree trunks or branches at the height of three meters.

As the effect of transplantation height on epiphyte growth in the lower stratum of the tropical forest was uncertain, we tested if there were differences in the performances of epiphytes transplanted into three different heights above the ground. We attached three transplants (ca. 0.25 g) of *Orthostichella rigida*, *Heterodermia leucomelos*, and *Usnea* sp., and one control net to each 3 m rope (C test ropes). We randomly organized 18 such ropes (with a total of 162 epiphyte transplants) into 6 sets of three ropes. We took two such sets to each of the three forest study sites and suspended them between tree trunks or branches at heights of 1.5 m, 3.5 m, and 5.5 m.

WEIGHING OF TRANSPLANTS.—We brought all test ropes back to the Taita Research Station for weighing twice, in May 2013 (toward the end of the long rains) and in January 2014 (toward the end of the short rains). We carried out the weighing systematically and as quickly as possible. We brought all transplants from one field site to the research station, allowed them to stabilize, weighed them, and then brought them back to the field, generally within 1 week.

The weight of bryophyte and lichen transplants is sensitive to even small changes in atmospheric humidity, temperature, and barometric pressure (McCune et al. 1996). Hence, we allowed the air-dried transplants to further stabilize indoors (unheated room) for 48 hours before weighing. We weighed some transplants from each set twice during the weighing session to detect possible changes in weight caused by changes in atmospheric humidity. In addition, we weighed the reference samples of each epiphyte species that had been stored indoors together with the field transplants, to detect any weight change in reference samples and to account for any systematic differences caused by seasonal differences in atmospheric humidity. In addition, we weighed all control nets each time together with the epiphyte transplants.

STATISTICAL ANALYSES.—We analyzed differences in growth among different species, sites, and time periods using fitted GLM with chi-square tests (*anova*(*glm*.model,test='Chisq'). While ANOVA and post hoc testing are often used for similar purposes, we chose a fitted GLM because it shows the sizes of the effects. The significant terms in GLM, as recognized by model comparisons and Chi-square tests, are expected to show similar significance in ANOVA and post hoc tests. We conducted all analyses using the R i386 3.2.4 (R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/).

RESULTS

DIFFERENCES IN EPIPHYTE WEIGHT CHANGE BETWEEN SITES AND SEASONS.—Figures 1 and 2 show the average change in biomass of the six transplanted epiphyte species at the three field sites. Significant increases in transplant biomass were recorded for three pendent moss species in Vuria (Figs. 1A–C). *Orthostichella rigida*, *O. capillicaulis*, and *Plagiochila* sp. also gained weight in Ngangao South (Figs. 1D and E, 2D), while all other epiphyte species at all other sites tended to lose weight during the experiment.

In *Orthostichella rigida* (Figs. 1A, D, G), the GLM analyses confirmed that forest site had a highly significant effect on weight change ($P < 0.0001$), whereas the effect of the time period was nonsignificant ($P = 0.648$). The combined effect was significant ($P < 0.003$). Pairwise comparisons confirmed the significance of differences in weight change between all sites (V–NG-S, $P < 0.02$; V–NG-N, $P < 0.0001$; NG-S–NG-N; $P < 0.0001$). When comparing differences in weight change between the two time periods separately for each forest site, the difference was highly significant in Ngangao North ($P < 0.0001$) and nonsignificant in Ngangao South ($P = 0.775$) and Vuria ($P = 0.131$).

In *Orthostichella capillicaulis* (Figs. 1B, E, H), the GLM analyses confirmed that forest site had a significant effect on weight change ($P < 0.031$), whereas the effect of the time-period was nonsignificant ($P = 0.474$). The combined effect was nonsignificant ($P = 0.952$). Pairwise comparisons confirmed the significance of differences in weight change between Vuria and Ngangao North ($P < 0.017$) and the two Ngangao sites ($P < 0.035$), but not between Vuria and Ngangao South ($P = 0.342$). When comparing differences in weight change between the two time periods separately for each forest site, the difference was nonsignificant at all sites (Ngangao North $P = 0.876$, Ngangao South $P = 0.481$, and Vuria $P = 0.653$).

In *Squamidium brasiliense* (Figs. 1C, F, I), the GLM analyses confirmed that forest site had a significant effect on weight change ($P < 0.002$), whereas the effect of the time period was nonsignificant ($P = 0.495$). The combined effect was significant ($P < 0.004$). Pairwise comparisons confirmed the significance of differences in weight change between Vuria and bot Ngangao sites (V–NG-S, $P < 0.007$; V–NG-N, $P < 0.002$), but not between the two Ngangao sites ($P = 0.767$). When comparing differences in weight change between the two time periods separately for each forest site, the difference was significant in Vuria ($P < 0.031$) and in Ngangao North ($P < 0.024$), but nonsignificant in Ngangao South ($P = 0.137$).

In *Plagiochila* sp. (Figs. 2A, D, G), the GLM analyses confirmed that neither the forest site ($P = 0.223$) nor time period ($P = 0.420$) had a significant effect on weight change. In addition, the combined effect was nonsignificant ($P = 0.06$), as were differences between sites in all pairwise comparisons (V–NG-S, $P = 0.178$; V–NG-N, $P = 0.112$; NG-S–NG-N; $P = 0.888$). When comparing differences in weight change between the two time periods separately for each forest site, the differences were nonsignificant in Ngangao North ($P = 0.05$) and in Vuria ($P = 0.197$), but significant in Ngangao South ($P < 0.045$).

In *Heterodermia leucomelos* (Figs. 1B, E, H), the GLM analyses confirmed that forest site did not have a significant effect on weight change ($P = 0.159$), whereas the effect of the time period was highly significant ($P < 0.0001$). The combined effect was nonsignificant ($P = 0.223$). Pairwise comparisons confirmed the significance of differences in weight change between Vuria and Ngangao North ($P < 0.032$), but not between Vuria and Ngangao South ($P = 0.46$) or between the two Ngangao sites ($P = 0.379$). When comparing differences in weight change between the two time periods separately for each forest site, the difference was significant in Vuria ($P < 0.003$), highly significant in Ngangao North ($P < 0.0001$), but nonsignificant in Ngangao South ($P = 0.440$).

In *Usnea* sp. (Figs. 2C, F, I), the GLM analyses confirmed that both the forest site had a significant effect on weight change ($P < 0.002$) and also the effect of the time period was highly significant ($P < 0.0001$). The combined effect was significant ($P < 0.005$). Pairwise comparisons confirmed the significance of differences in weight change between Vuria and Ngangao North (P <

0.002), but not between Vuria and Ngangao South ($P = 0.138$) or between the two Ngangao sites ($P = 0.065$). When comparing differences in weight change between the two time periods separately for each forest site, the difference was highly significant in Vuria ($P < 0.0001$), but nonsignificant in Ngangao North ($P = 0.06$), and in Ngangao South ($P = 0.516$).

EFFECT OF TRANSPLANT SIZE AND TRANSPLANTATION HEIGHT.—In *Orthostichella rigida*, the GLM analyses showed that the overall differences in weight change between the three different size classes were statistically nonsignificant ($P = 0.067$). However, pairwise comparisons at each site revealed that in Ngangao South, medium- sized transplants lost significantly more weight than either the small transplants ($P < 0.001$) or the large transplants ($P < 0.02$), and also that the differences between small and large transplants were statistically significant ($P < 0.05$). In Ngangao North none of the observed differences in weight loss between the different transplant size classes were statistically significant ($P = 0.359$). In Vuria large transplants gained significantly less weight than small transplants ($P < 0.05$), but the differences between small and medium transplants ($P = 0.335$) and between medium and large transplants ($P = 0.837$) were nonsignificant.

In addition, in *Heterodermia leucomelos* the overall differences in biomass change between the three transplant size classes were statistically nonsignificant (GLM, $P = 0.083$). Pairwise comparisons between the size classes at each site revealed that transplant size had a statistically significant effect on transplant weight change only in Ngangao South, where medium transplants lost significantly more weight than large transplants ($P < 0.0001$).

Differences in weight changes in epiphyte transplants that were placed into three different heights (1.5 m, 3.5 m, and 5.5 m) in the lower canopy of each study site were not statistically significant for any of the three epiphytes used in the experiment: *Orthostichella rigida* ($P = 0.94$), *Heterodermia leucomelos* ($P = 0.197$), and *Usnea* sp. ($P = 0.804$). Pairwise comparisons between height classes at each site confirmed that transplantation height did not have a statistically significant effect on weight change in any transplanted species.

CONTROLS AND TRANSPLANT LOSSES DURING EXPERIMENT.—Weighing the control specimens of each transplanted species together with transplants returned from the field showed that possible differences in ambient air humidity at the times of weighing had no measurable effect on the weight of the transplants. Furthermore, the transplant rigging samples (empty nets with rigging) confirmed that the weight of the plastic riggings did not change over the time course of the transplant experiment.

Eight percent were lost in the course of the 1 yr experiment. Six percent of the transplants were lost through fragmentation (epiphyte biomass gone, but rigging left) and two percent of transplants had disappeared altogether. The species most resistant to fragmentation and detachment were *Orthostichella rigida* (1% of transplants fragmented) and *Squamidium brasiliense* (2% of transplants fragmented), while *Usnea* sp. (13% of transplants fragmented) was most prone to fragmentation.

DISCUSSION

In this work, we used pendant transplants to document the growth of tropical epiphytic bryophytes and lichens using pendant transplants. We found significant differences in performances of all studied epiphyte species among the three forest sites. In general, epiphytic bryophytes grew more than epiphytic lichens, and all studied mosses maintained or increased their biomass when transplanted into the cool and humid upper montane forest of Vuria. Many transplants of Orthostichella rigida more than doubled their initial weight within 1 yr (Fig. S2—Online Supplementary Material). This demonstrates that under favorable conditions tropical bryophytes can exhibit growth rates comparable to some epiphytic bryophytes and lichens of temperate rainforests, where recorded average annual biomass growth rates are typically between 5 and 40 percent, with maximal values sometimes exceeding 150 percent (e.g., McCune et al. 1996, Sillett et al. 2000, Rosso et al. 2001, Antoine & McCune 2004, Muir et al. 2006).

Transplant losses were generally low, which was somewhat surprising especially considering that monkeys (*Chlorocebus pygerythrus* and *Cercopithecus albogularis*) are common in Ngangao Forest. The monkeys did not seem to find our transplants interesting as only 2 percent of all transplants disappeared without a trace. Before the experiment, we identified monkeys as a potential threat and thus decided to use green plastic net for constructing the transplants instead of the more commonly available red net, which could have been attractive to curious primates.

The negative growth of most transplants to Ngangao Forest confirmed that the lower canopy of lower montane forests represents a poor habitat for all the studied epiphyte species. Canopy height in the southern part of Ngangao Forest was much higher than in the northern part (Fig.

S1—Online Supplementary Material) and rainfall was somewhat higher as well (Table 1). The more shaded and humid microclimate of the southern site may explain why all three pendent moss species performed better there than in the north, and demonstrates that even relatively small differences in forest microclimate can influence the performance of pendent bryophytes in montane tropical forests. Dense canopy shading reduces the amount of photosynthetically active light and modifies light quality, but also helps to maintain high humidity by reducing evapotranspiration, which is beneficial for pendant bryophytes.

The performance of both transplanted lichen species contrasted clearly to that of the pendant mosses, with best performance recorded in the relatively dry northern part of Ngangao Forest. Especially during the dry season the relatively low canopy at this site allows some direct sun light to penetrate into the lower sections of the canopy and even reach the forest floor. Many epiphytic lichens are known to thrive in microhabitats that combine at least moderate light levels with relatively high humidity (e.g., Rikkinen 1995, Zotz & Schleicher 2003, Antoine & McCune 2004, Dyer & Letourneau 2005, Gauslaa et al. 2006), and insufficient light levels may largely explain why such species tend to perform poorly under closed forest canopies (e.g., Pardow et al. 2010, Gehrig-Downie et al. 2011, Hylander et al. 2013).

Considering the overall habitat preferences of all transplanted epiphyte species in Taita Hills, it seems unlikely that their relatively poor performance in Ngangao Forest would be due to any single environmental factor, such as insufficient levels of photosynthetically active irradiation per se, but rather due to a detrimental combination of several factors, linked to inherent difficulties in maintaining positive net photosynthesis and growth in warm, periodically moist, and permanently shaded habitats. Such conditions, which closely correspond to those experienced by the epiphyte transplants in Ngangao Forest, are likely to periodically subject the epiphytes to high respiration losses. Meanwhile, the same species in the upper canopy and in edge habitats typically dry up and become inactive; and transplants in the constantly moist but significantly cooler Vuria Forest are able to maintain positive growth due to relatively low respiration losses. It is well established that in lowland rainforests a similar combination of excessive moisture and heat, coupled with insufficient light, seriously hinders the success of most epiphytic bryophytes and macrolichens (e.g., Lakatos et al. 2006, Wagner et al. 2014a, b, He et al. 2016).

The three height classes used in our study were not distinct enough to induce significant differences in epiphyte growth. From the perspectives of our transplants, all three heights were within the same, relatively unfavorable ‘low canopy’ environment. In other studies bryophyte and lichen transplants have been placed much higher into the forest canopy. For example, Antoine and McCune (2004) hung their lichen transplants 3–43 m high into the canopy of a temperate rainforest and recorded the best growth rates at 30–40 m. The general inaccessibility of the upper canopy of mature tropical forests explains why information on the diversity of cryptogamic tree crown epiphytes is still fragmentary at best (e.g., Normann et al. 2010, Sporn et al. 2010).

In conclusion, epiphyte transplants can be successfully used for documenting growth of epiphytic bryophytes and lichens in tropical forests. Growth responses of different epiphyte species collected from upper montane forests clearly differed when transplanted into upper and lower montane forests. The start weight of 0.25 g for transplants worked well and can thus be recommended for future studies, but in the lower canopies of montane forests in the Taita Hills a vertical gradient of five meters is not sufficient to induce clear differences in epiphyte growth. The transplant losses (8% of transplants lost) experienced during our study were comparatively low when compared to those reported in previous studies in temperate forests (e.g., McCune et al. 1996, Peck et al. 2000). Of the six transplanted epiphyte species, *Orthostichella rigida* and *Squamidium brasiliense* were most resistant against fragmentation and detachment, while *Usnea* sp. was most prone to fragmentation.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article: FIGURE S1. The study sites in the Taita Hills. FIGURE S2. Photograph showing examples of epiphyte transplants in Vuria.

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TABLES

TABLE 1. Climatic differences between the study sites. T avg, average diurnal temperature (°C); T min, average diurnal minimum (°C); T max, average diurnal maximum (°C); RH avg, average diurnal atmospheric humidity (%); RH min, average diurnal minimum of atmospheric humidity (%). The last three columns show total precipitation (mm) for January–December 2013 and for January–May and June–December, respectively. The temperature and humidity values for Vuria, Ngangao South (NG-S), and Ngangao North (NG-N) are based on iButton data collected between May 2013 and March 2014. These data should be understood to only tentatively characterize climatic conditions under the forest canopy at each site. Concurrent data from Mwanda, a weather station in open agricultural land near Vuria (1 672 m asl) are given for comparison (Source: TAITAWATER).

Site	**T avg**	**T min**	**T max**	**RH avg**	**RH min**	**Rain**	**Rain Jan-May**	**Rain Jun-Dec**
Vuria	12.28	10.27	14.82	98.61	91.31	1283	558	725
NG-S	13.97	12.12	16.24	96.99	84.97	963	448	515
NG-N	14.64	12.27	18.21	93.73	78.94	943	381	562
Mwanda	18.28	14.59	25.50	72.92	47.03	807	409	398

FIGURES

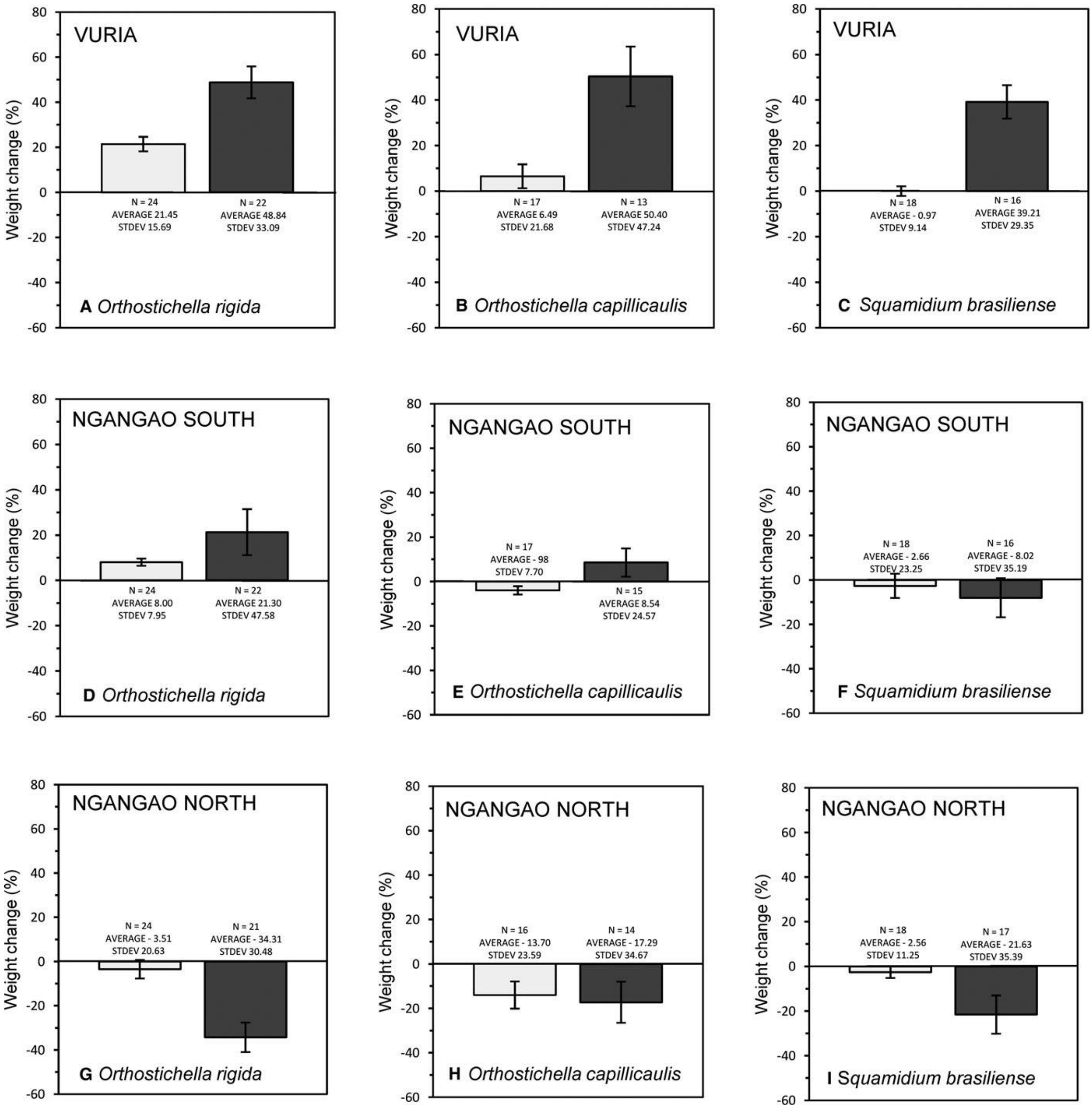

FIGURE 1. Average change in biomass of three pendant moss species (*Orthostichella rigida*, *O. capillicaulis*, *Squamidium brasiliense*) transplanted to Vuria, Ngangao South and Ngangao North. The light bars show the change in biomass in January–May 2013 (incl. long rains) and the dark bars show the change in biomass in June–December 2013 (incl. short rains).

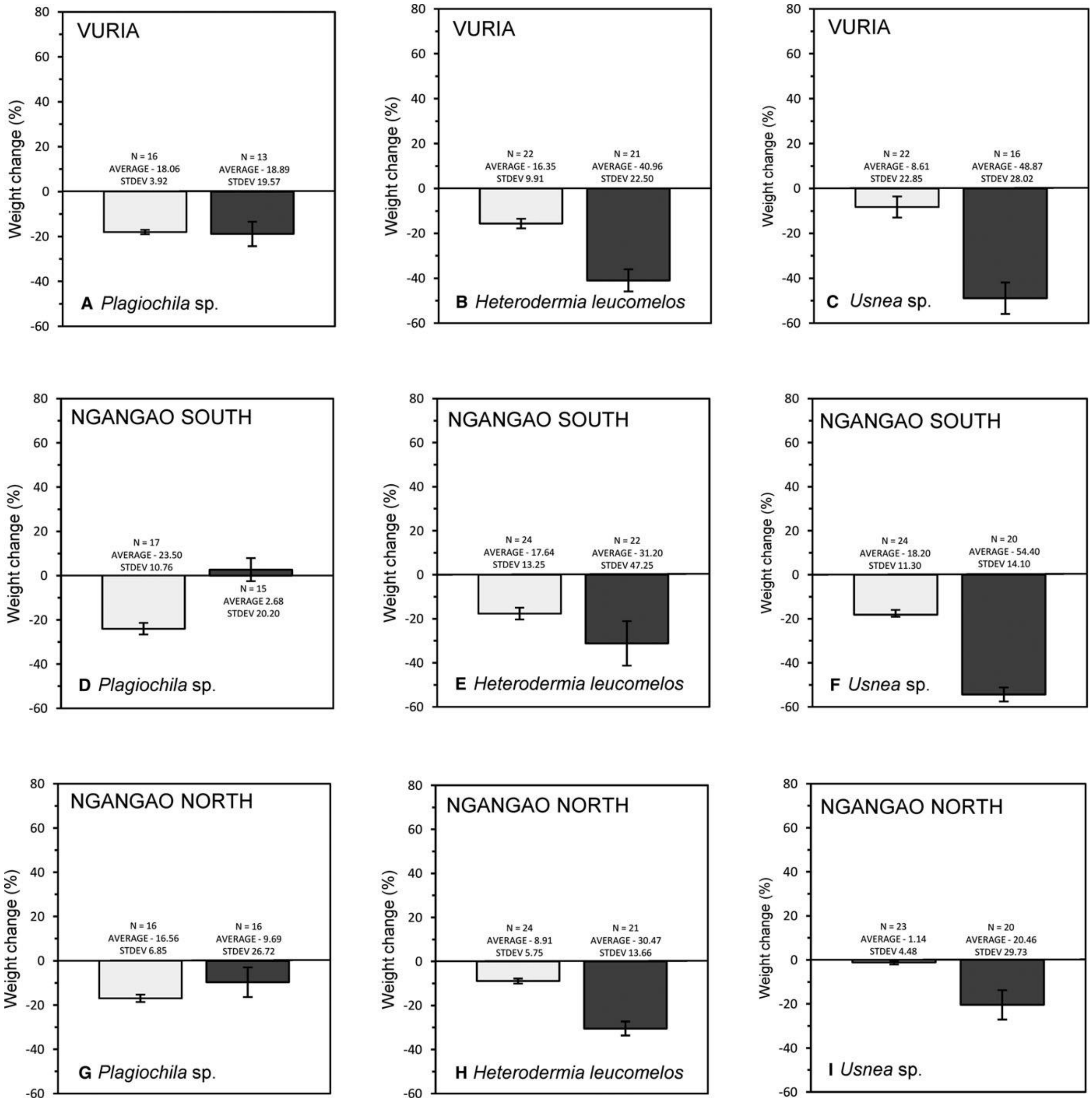

FIGURE 2. Average change in biomass of one leafy liverwort taxon (*Plagiochila* sp.) and two lichen taxa (*Heterodermia leucomelos*, *Usnea* sp.) transplanted to Vuria, Ngangao South and Ngangao North. The light bars show the change in biomass in January–May 2013 (incl. long rains) and the dark bars show the change in biomass in June–December 2013 (incl. short rains).

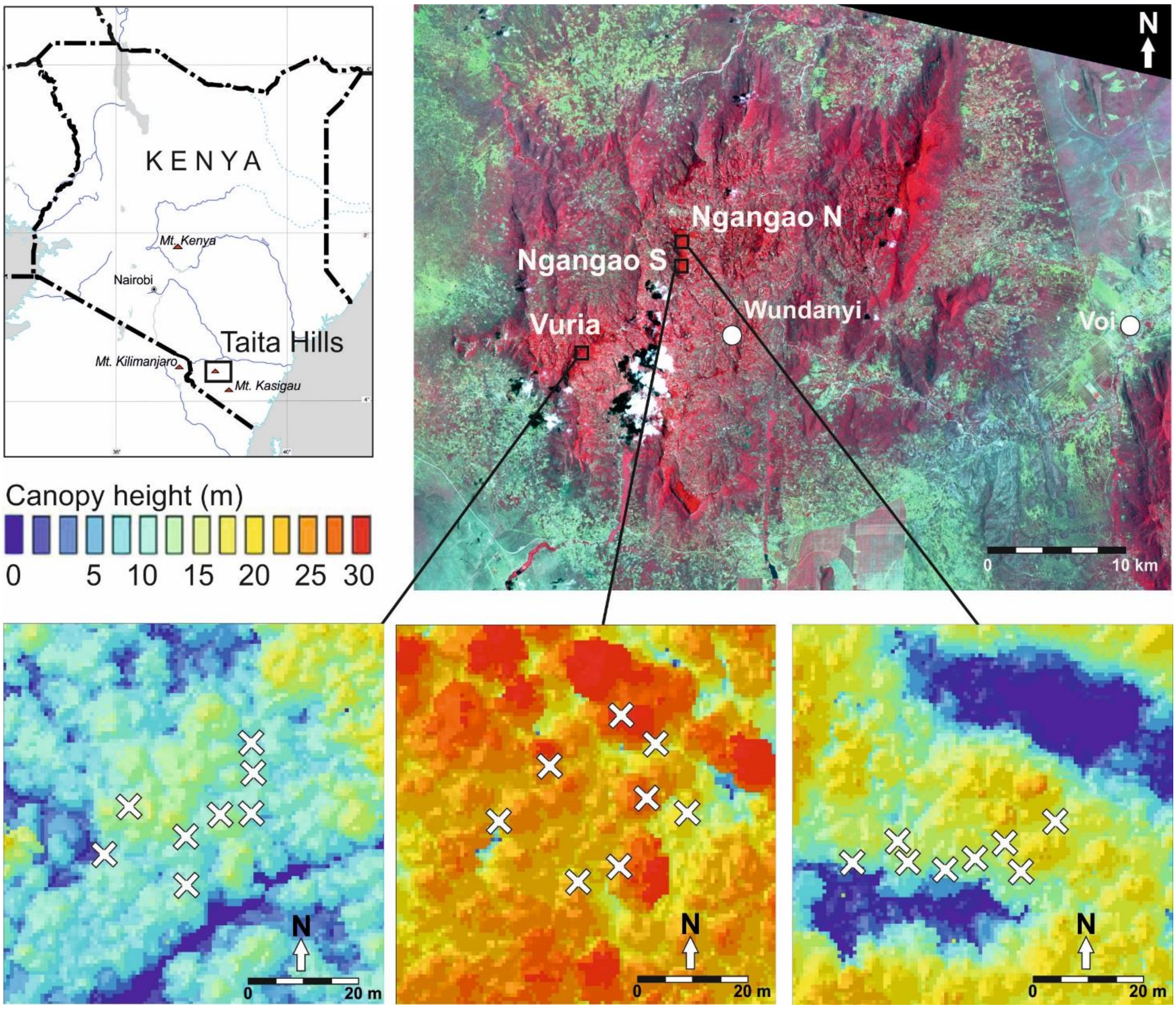

FIGURE S1. The study sites in the Taita Hills. The satellite image (SPOT XS) is a false-color composite in which green vegetation appears in different shades of red (due to high reflectance in the NIR band). The LiDAR images of the three forest plots illustrate variation in canopy density and canopy height, with different colors showing canopy height in meters (see legend in figure). The white crosses indicate the approximate placement of epiphyte transplants (test ropes) in the lower forest canopy at each study site.

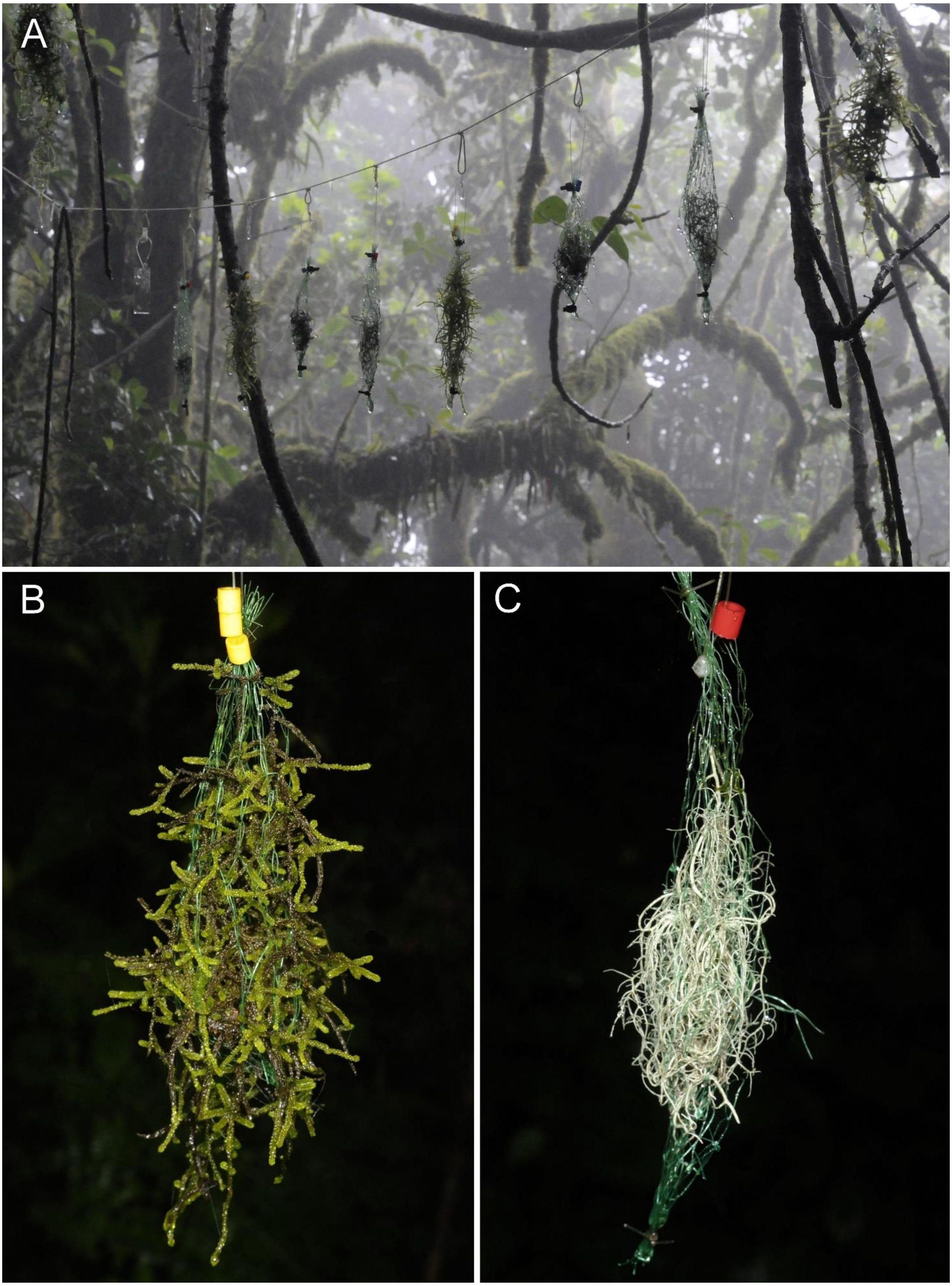

FIGURE S2. Examples of well-growing epiphyte transplants in Vuria (photographed Sept 14, 2013). A. Test rope with pendant transplants suspended between two tree trunks in the lower canopy of the upper montane cloud forest. B. Transplant OrVH5315 (*Orthostichella rigida*) increased in dry weight by 15.5 percent in January–May 2013 and by 100.7 percent in June–December 2013 (total increase of dry weight 131.8%). C. Transplant UsVH5115 (*Usnea* sp.) increased in dry weight by 0.8 percent in January–May 2013 and 3.4 percent in June–December 2013 (total increase of dry weight 4.2%).